United States Patent [19]
Leitch

[11] Patent Number: 4,816,783
[45] Date of Patent: Mar. 28, 1989

[54] METHOD AND APPARATUS FOR QUADRATURE MODULATION

[75] Inventor: Clifford D. Leitch, Coral Springs, Fla.

[73] Assignee: Motorola, Inc., Schaumburg, Ill.

[21] Appl. No.: 141,757

[22] Filed: Jan. 11, 1988

[51] Int. Cl.[4] H03C 1/00
[52] U.S. Cl. 332/41; 332/48; 375/39
[58] Field of Search .... 332/31 R, 41, 42, 48; 455/59, 60, 95, 108; 375/39

[56] References Cited

U.S. PATENT DOCUMENTS

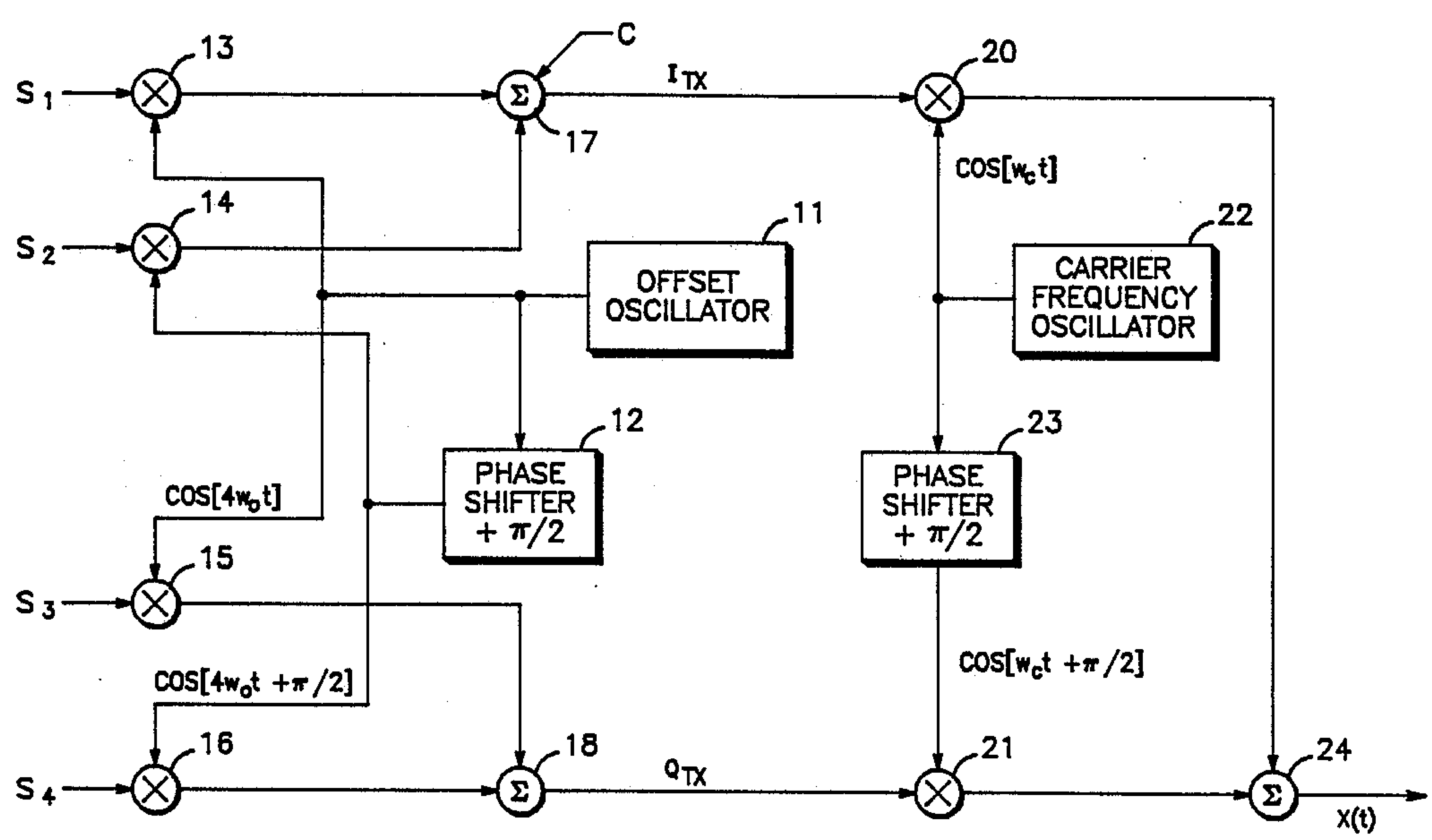
2,960,573	11/1960	Hodgson et al.	179/15
3,082,296	3/1963	Caruthers	370/20
3,511,936	5/1970	Saltzberg	370/20
3,514,701	5/1970	Palatinus	370/20
3,821,798	6/1974	Cannon	370/74
4,313,211	1/1982	Leland	455/139
4,398,216	8/1983	Field et al.	370/20
4,521,878	6/1985	Toyonaga	455/60 X
4,626,803	12/1986	Holm	332/9 R
4,675,619	6/1987	Uchibori et al.	332/31 R
4,680,777	7/1987	Saha	375/53
4,696,017	9/1987	Masheff et al.	375/60

Primary Examiner—Eugene R. LaRoche
Assistant Examiner—Robert J. Pascal
Attorney, Agent, or Firm—Daniel K. Nichols

[57] ABSTRACT

A quadrature amplitude modulation system utilizes two subcarrier signals, each quadrature modulated with information signals which are quadrature modulated onto the RF carrier. This provides a hole in the center of frequency spectrum, permitting carrier and bit sync signals can be provided in the center area of the signal spectrum.

11 Claims, 6 Drawing Sheets



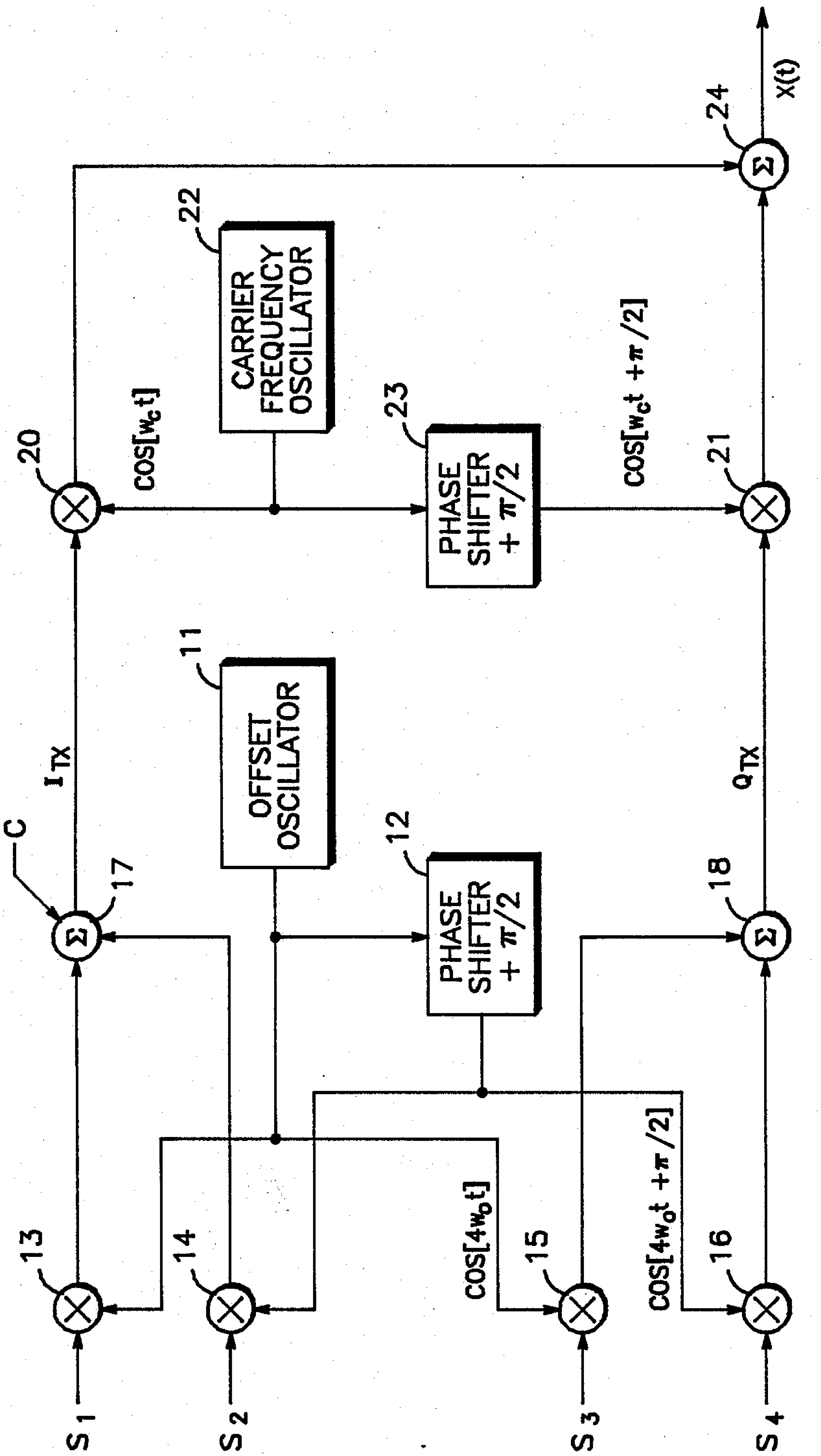

CARRIER FREQUENCY OSCILLATOR
OFFSET OSCILLATOR
PHASE SHIFTER + π/2
PHASE SHIFTER + π/2
cos[$w_c t$]
cos[$w_c t + \pi/2$]
cos[$4w_o t$]
cos[$4w_o t + \pi/2$]
I_{TX}
Q_{TX}
x(t)
S_1
S_2
S_3
S_4
C
11
12
13
14
15
16
17
18
20
21
22
23
24

FIG. 1

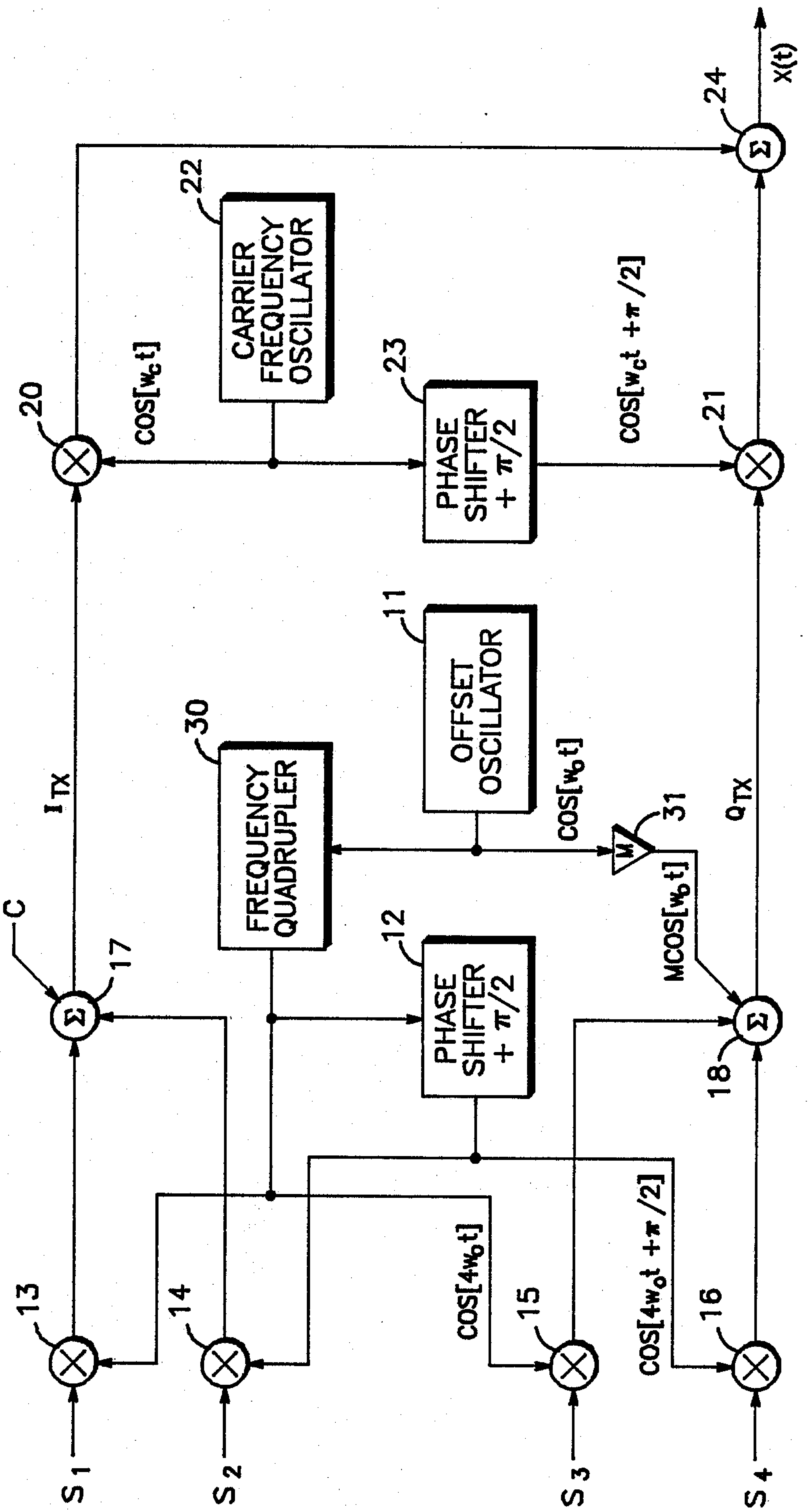
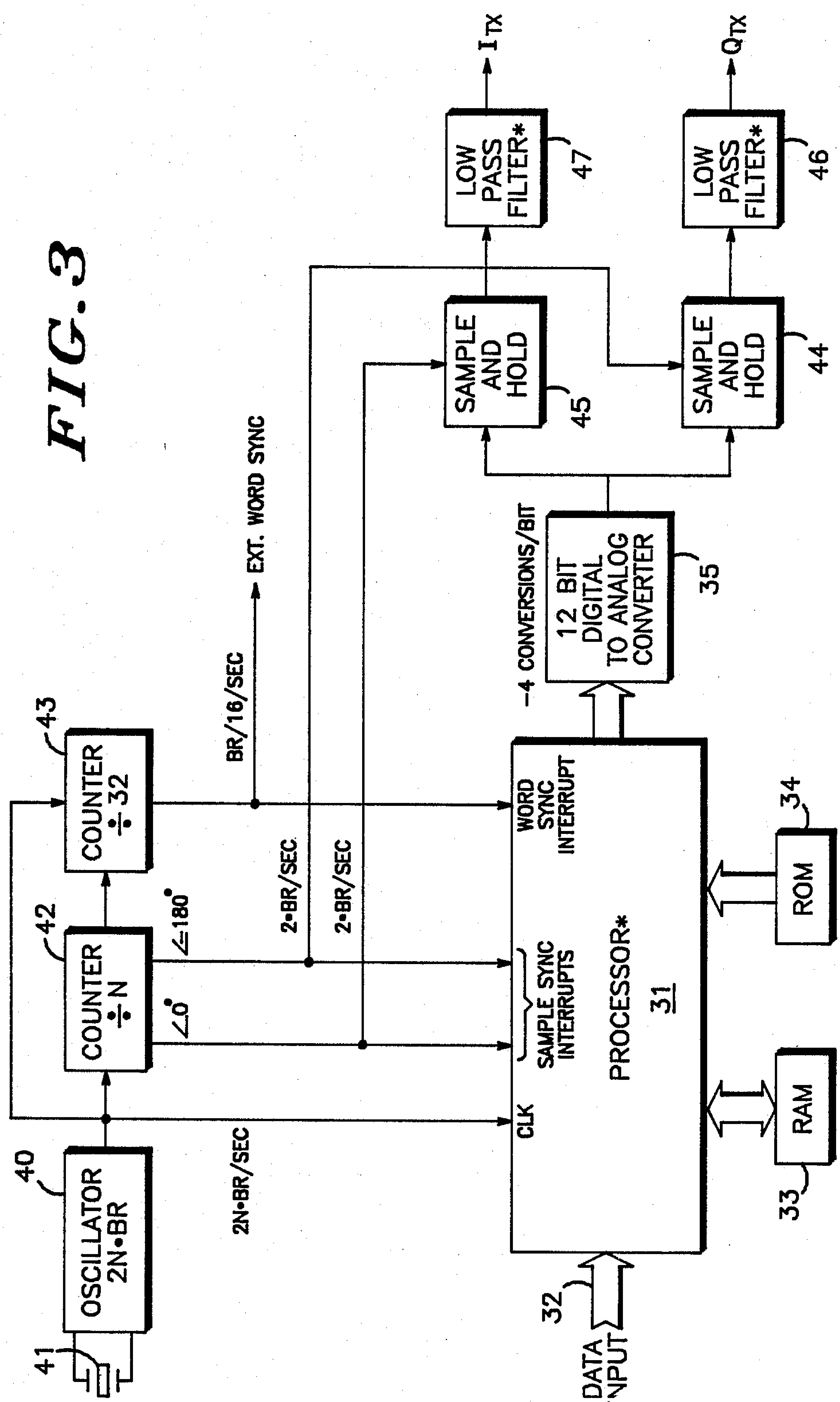

CARRIER FREQUENCY OSCILLATOR
PHASE SHIFTER + π/2
OFFSET OSCILLATOR
FREQUENCY QUADRUPLER
PHASE SHIFTER + π/2
COS[w_ct]
COS[w_ct +π/2]
COS[w_ot]
MCOS[w_ot]
COS[4w_ot]
COS[4w_ot +π/2]
I_{TX}
Q_{TX}
X(t)
C
M
S_1
S_2
S_3
S_4
11
12
13
14
15
16
17
18
20
21
22
23
24
30
31

FIG. 2

FIG. 3



OSCILLATOR 2N•BR
40
41
COUNTER ÷ N
42
COUNTER ÷ 32
43
2N•BR/SEC
∠0°
∠180°
2•BR/SEC
2•BR/SEC
BR/16/SEC
EXT. WORD SYNC
CLK
SAMPLE SYNC INTERRUPTS
WORD SYNC INTERRUPT
PROCESSOR*
31
DATA INPUT
32
RAM
33
ROM
34
~4 CONVERSIONS/BIT
12 BIT DIGITAL TO ANALOG CONVERTER
35
SAMPLE AND HOLD
45
SAMPLE AND HOLD
44
LOW PASS FILTER*
47
LOW PASS FILTER*
46
I_{TX}
Q_{TX}

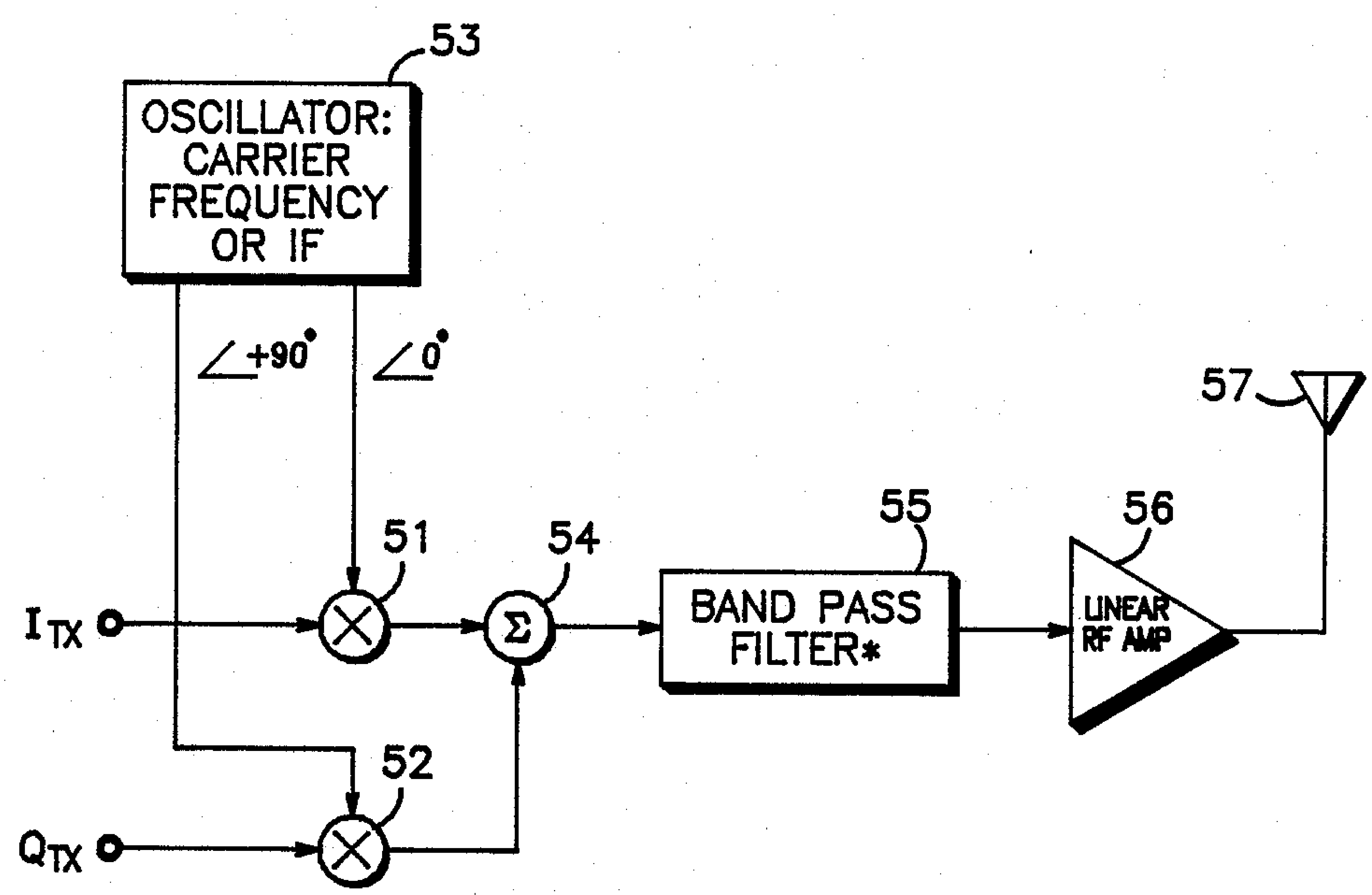

53
OSCILLATOR: CARRIER FREQUENCY OR IF
+90°
0°
57
55
56
51
54
I_{TX}
BAND PASS FILTER*
LINEAR RF AMP
52
Q_{TX}

FIG. 4

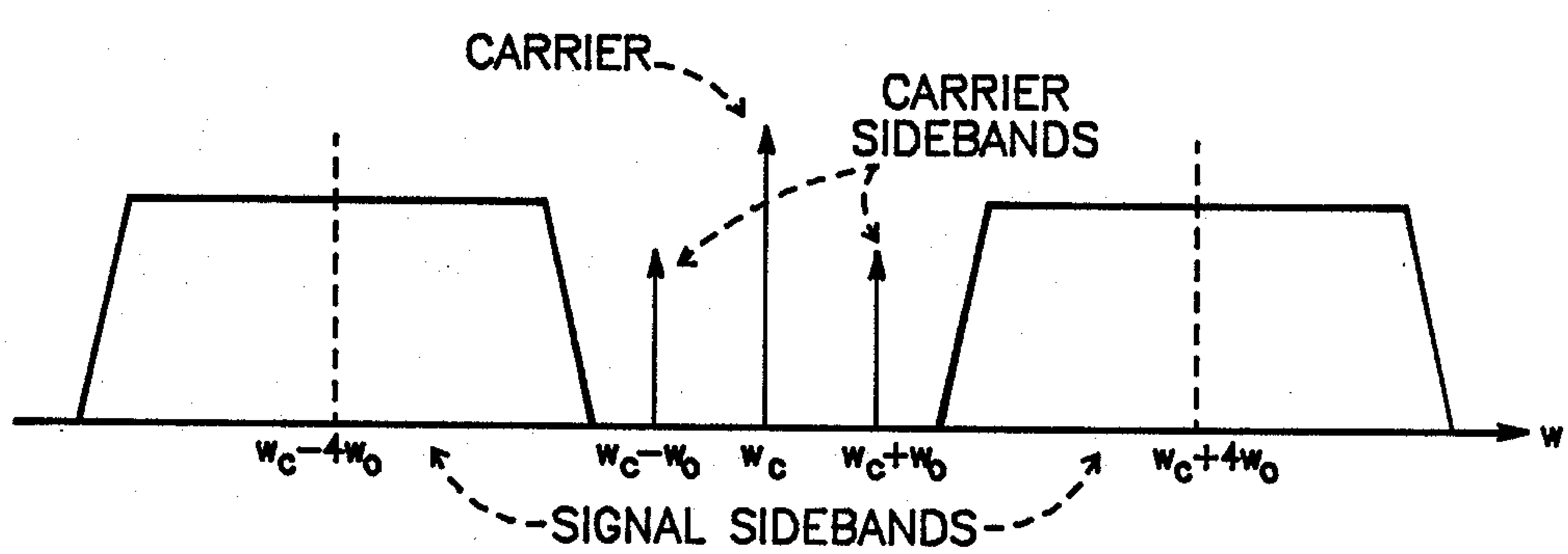

CARRIER
CARRIER SIDEBANDS
w_c-4w_o
w_c-w_o
w_c
w_c+w_o
w_c+4w_o
w
SIGNAL SIDEBANDS

FIG. 5

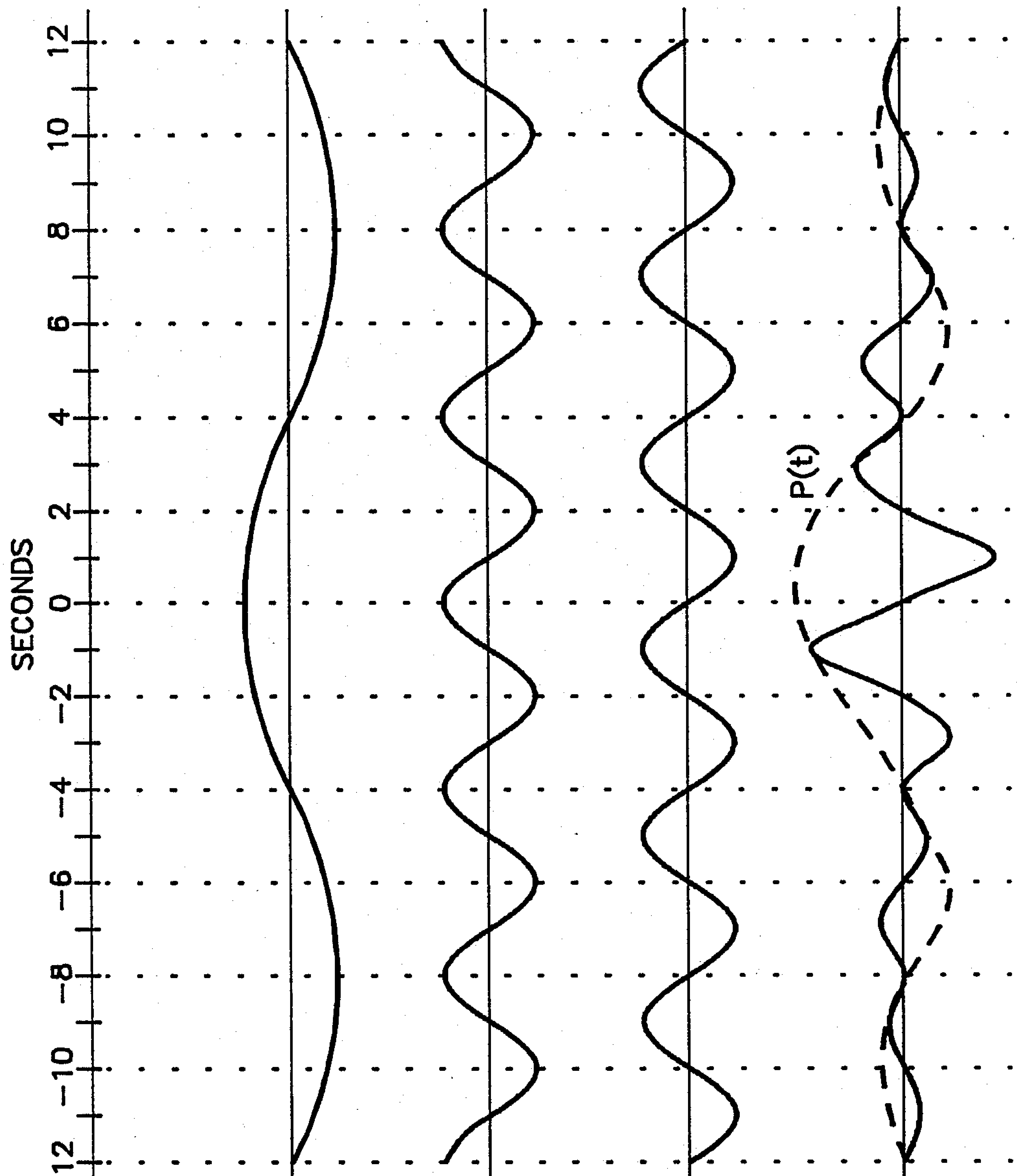


FIG. 6A $w_o = 2\pi/16$

FIG. 6B $\cos[w_o t]$

FIG. 6C $\cos[4 w_o t]$

FIG. 6D $\cos[4 w_o t + \pi/2]$

FIG. 6E $P(t)\cos[4 w_o t + \pi/2]$

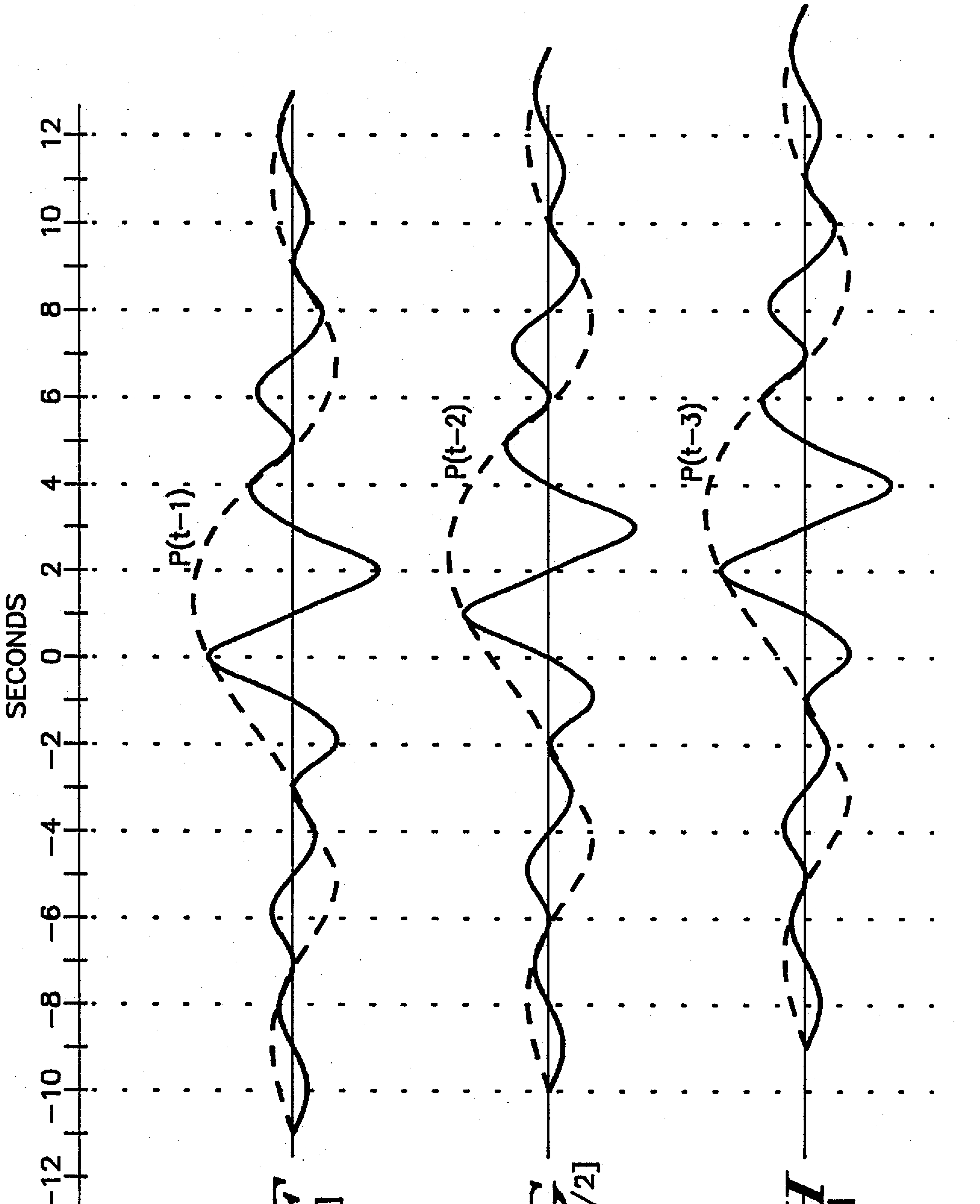


FIG. 6F P(t-1)cos[4w$_o$t]

FIG. 6G P(t-2)cos[4w$_o$t+π/2]

FIG. 6H P(t-3)cos[4w$_o$t]

METHOD AND APPARATUS FOR QUADRATURE MODULATION

BACKGROUND OF THE INVENTION

This invention relates to quadrature amplitude modulation systems in general and particularly to a system in which signal components are modulated unto a subcarrier to allow for inclusion of carrier and bit sync information at the center of the transmitted frequency spectrum. In a quadrature modulation system, designed for radio transmission, it is desirable to transmit a pilot carrier in order to facilitate reception and decoding of the transmitted information. While it is known to transmit a pilot carrier, such carriers have been added as a side frequency to the quadrature amplitude modulated signal. There are, however, limitations and disadvantages to this approach. Due to selectively fading, such as can occur on a radio path, problems can result where the pilot carrier is spaced from the signal information. Additionally, problems can occur due to limitations in the passband of receivers i that the pilot carrier signal may fall too close to or outside of receiver's passband filter edge. Consequently, it is desirable that such a pilot carrier be located more centrally to the transmitted frequency spectrum.

Where digital information is to be transmitted in a synchronous manner, channel fading and noise can prevent the maintenance of bit sync. In such a system it is therefore desirable to transmit a bit sync signal with the synchronous digital information. Like the pilot carrier, the bit sync signal should be provided as close to the center of the transmitted frequency spectrum as possible.

SUMMARY OF THE INVENTION

This method and apparatus for a quadrature amplitude modulation permits the inclusion of both the carrier pilot and bit sync signals at and adjacent to the center of the signal spectrum.

A method of transmitting a quadrature amplitude modulated signal including the steps of: quadrature modulating first and second signals onto a subcarrier; quadrature modulating third and fourth signals onto a subcarrier; quadrature modulating the first and second quadrature modulated subcarriers onto a carrier; and tranmitting the quadrature modulated carrier.

In one aspect of the invention, the method includes the further step of providing a DC component with one of the quadrature modulated subcarrier to produce a pilot carrier. In another aspect of the invention, the method includes the further step of providing a bit sync signal with one of said quadrature modulated subcarriers. In still another aspect of the invention, the signals are digital signals having a predetermined bit rate and the bit sync signal has a frequency that is an integral submultiple of the bit rate.

In still another aspect of the invention, a method of transmitting a quadrature amplitude modulated signal includes the steps of reading from memory first and second prototype pulses each including a subcarrier component, summing the first and second prototype pulses to produce a first quadrature modulated subcarrier, reading from memory third and fourth prototype pulses each including a subcarrier component, summing said third and fourth prototype pulses to produce a second quadrature modulated subcarrier, quadrature modulating a carrier with said first and second quadrature modulated subcarriers and transmitting the quadrature modulated carrier.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram of a quadrature amplitude modulation system in accordance with the present invention, particularly suitable for the transmission of analog signals.

FIG. **2** is a block diagram of another quadrature amplitude modulation system in accordance with the present invention, particularly suitable for the transmission of digital signals.

FIG. **3** is a schematic block diagram of another quadrature amplitude modulation system in accordance with the present invention, which utilizes predetermined pulse waveforms.

FIG. **4** is a schematic block diagram of a the transmitter backend for use with the system of FIG. **3**.

FIG. **5** is a graphical representation of the frequency spectrum of a quadrature modulated signal with a pilot carrier and bit sync signals in accordance with the present invention.

FIG. **6A** is a time line normalized for 1 bit per second.

FIG. **6B** is a graphical representation of the offset oscillator output cos (w_0t).

FIG. **6C** is a graphical representation of the frequency quadrupler output or subcarrier cos ($4w_0t$).

FIG. **6D** is a graphical representation of the phase shifter output or quadrature subcarrier cos ($4w_0t+Pi/2$).

FIG. **6E** is a graphical representation of the S2 channel pulse P(t) modulated on the quadrature subcarrier of FIG. **6D**.

FIG. **6F** is a graphical representation of the S1 channel pulse P(t−1) modulated on the subcarrier of FIG. **6C**.

FIG. **6G** is a graphical representation of the S4 channel pulse P(t−2) modulated on the quadrature subcarrier of FIG. **6D**.

FIG. **6H** is a graphical representation of the S3 channel pulse P(t−3) modulated on the subcarrier of FIG. **6C**.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now by characters of reference to the drawings and first to FIG. **1**, a quadrature modulation system is shown which is capable of providing a pilot carrier signal in the center of the signal spectrum. Four input signals **S1-S4** which can be independent analog and/or digital signals are combined. This particular system is most suitable for analog signals as no provision is made for insertion of bit sync information.

An offset oscillator **11** is used to provide a subcarrier signal cos[w_0t]. Its output is also provided to a **90** degree phase shifter **12** which provides a quadrature subcarrier signal cos($w_0t+Pi/2$). The four input signals **S1-S4** are applied to mixer or multiplier circuits **13-16** respectively. The subcarrier signal from oscillator **11** is applied to mixers **13** and **15** while the quadrature subcarrier signals, from phase shifter **12** is applied to mixers **14** and **16**. The outputs of mixers **13** and **14** are combined at summer **17**, while the outputs of mixer **15** and **16** are combined at summer **18**. The output of summer **17** is the I_{tx} or in-phase signal for modulation on the RF carrier and the output of summer **18** is the Q_{tx} or quadrature signal for quadrature modulation on the RF carrier. Mixers **13** and **14** and summer **17** constitute means for quadrature modulating first and second signals on a first subcarrier while mixers **15** and **16** and summer **18** constitute means for quadrature modulating third and fourth signals on a second subcarrier.

When it is desired to provide a pilot carrier signal for transmission with the quadrature modulated signals, a DC offset voltage, having a magnitude C, is applied to one of the summers **17** and **18**. In this embodiment, DC voltage is applied to the summer **17**. The outputs of summers **17** or **18** are provided to mixer or multipliers **20** and **21** respectively. A carrier frequency oscillator **22** provides an in phase carrier signal $\cos(w_c t)$ which is applied to the mixer **20** and to the input of a **90** degree phase shifter **23**. The output of phase shifter **23**, which is the quadrature carrier signal $\cos(w_c t+Pi/2)$, is applied to the mixer **21**. The outputs of mixers **20** and **21** are provided to a summing circuit **24** to produce the combined transmit signal X(t). The X(t) signal can then be applied as through a bandpass filter and amplifier to an antenna, which constitute means for transmitting the quadrature modulated carrier, for radio transmission as is discussed subsequently in regard to FIG. **4**. The mixers **20** and **21** and summer **24** constitute means for quadrature modulating the subcarriers onto a carrier.

When digital signals are to be transmitted, it is desirable to provide a bit sync signal. The bit sync signal can be provided as sideband signals to the carrier signal and be located in the frequency spectrum between the quadrature signals. A system suitable for digital communication is illustrated in FIG. **2**. The parts of FIG. **2** which are identical to the parts of FIG. **1** are indicated with the same reference numeral. The principal difference involves the offset oscillator arrangement. In this case, the offset oscillator **11** provides an output frequency w_0 which is one quarter of the oscillator frequency of FIG. **1**. The frequency w_0 is chosen as an integer submultiple of the bit rate and in the preferred embodiment is one-fourth of the bit rate of each of the subchannels (one-sixteenth of the total bit rate). The output of offset oscillator **11** of FIG. **2** is applied to a frequency quadrupler **30** for application to the phase shifter **12** and mixers **1314** **16** in a manner identical to FIG. **1**. However, the lower frequency signal of offset oscillator **11** is also applied to a amplifier **31** having an amplification factor equal to M. Its output is applied, in this case, to the summer **18** constituting means for summing a sync signal with one of the subcarriers. It will be understood that the output of amplifier **31** could be applied to the summer **17** and the carrier signal C applied to the summer **18** if desired or both to the same summer. The I_{tx} and Q_{tx} signals are then quadrature modulated on the carrier frequency as in FIG. **1**. The output signal X(t) includes not only the quadrature modulated signal components but also a carrier and bit sync sidebands as illustrated in FIG. **5**. The S1–S4 signals are preferably predetermined pulses P(t) read from a memory ROM, such as it is disclosed in co-pending U.S Pat. No. 4,737,969, issued Apr. 12, 1988, and owned by the assignee of this invention, the disclosure of which is incorporated by reference as if fully set out herein.

When using stored pulses, the mixing or multiplication step of mixers **13–16** can be eliminated by reading from memory pulses representative of the product of the multiplication or mixing, provided the bit rate and subcarrier frequency are related by an integer ratio.

FIG. **3** illustrates a microprocessor based system for providing the I_{tx} and Q_{tx} signals. In this case a digital signal processor **31**, constituting processor means, includes a data input **32** for receiving the digital data to be transmitted. The digital data can be four independent digital data stream or preferably a single data stream can be subdivided as the S1–S4 signals. The processor **31** includes RAM **33** and ROM **34**. The ROM **34** includes the preprogrammed waveforms which are be summed to provide the I_{tx} and Q_{tx} signals. The I_{tx} signal is produced by adding an **S1** stored pulse corresponding to $P(t-1)\cos(4w_0t)$ of FIG. **6F** to an S2 signal corresponding to $P(t)\cos(4w_0t+Pi/2)$ of FIG. **6E** along with the carrier amplitude constant C. Similarly for the Q_{tx} signal, the S3 signal $P(t-3)\cos(4w_0t)$ and the S_4 stored pulse $P(t)\cos(4w_0t+Pi/2)$ of FIG. **6G** are added along with the bit sync signal $M\cos(4w_0t)$. The process continues similarly for each successive set of 4 bits. It will be appreciated that for a binary system it is only necessary to store one prototype pulse. It is negated to represent the other binary signal. Also as illustrated in FIGS. **6E–6H**, the same waveform is used on each channel S1–S4 differing only in phase or time. While the preferred embodiment utilizes binary or two level signals, multilevel (e.g. 8 level) signals could be provided on each channel to increase information throughput. It would then be necessary to store four pulses for an **8** level signal since their negatives would represent the other four levels which can be easily computed by the processor **31**.

The output of processor **31** is applied to a **12** bit D/A converter **35**. An oscillator circuit **40**, having a crystal, **41** provides an output frequency equal to $2N\times$Bit Rate which is applied to the clock input of processor **31** and the clock inputs of counters **42** and **43**. Counter **42**, constituting a divide by N counter, provides **0** degree and a -180 degree outputs, which are applied to the processor **31** as a sample sync interrupts and are also applied to sample and hold circuits **44** and **45**, respectively. These are at twice the bit rate to permit the single D/A converter **35** to be used for both the I_{tx} and Q_{tx} signals. The inputs of sample and hold circuits **44** and **45** are connected to the output of the D/A converter **35**. Low pass filters **46** and **47** are connected to the outputs of the sample and hold circuits **44** and **45** with their outputs providing the Q_{tx} and I_{tx} transmit signals. These are then quadrature modulated on the carrier frequency w_c as in FIG. **1** and **2**. In this embodiment, a Texas Instruments TMS 32020 Digital Signal Processor can be utilized. The object code including the prototype pulse information as stored in ROM **34** is given in Table 1, which is appended hereto.

Referring now to FIG. **4**, the radio backend for quadrature modulation of the I_{tx} and Q_{tx} signals of FIG. **3** onto a carrier, is illustrated. The I_{tx} and Q_{tx} signals are applied to mixers **51** and **52** respectively which correspond to the mixers **20** and **21** of FIGS. **1** and **2**. The carrier and 90 degrees quadrature carrier signals are provided to mixers **51** and **52** respectively, as by carrier frequency oscillator **53** which corresponds to the carrier frequency oscillator **22** and phase shifter **23**. The output of mixers **51** and **52** are applied to a summer **54** whose output provides the transmit signal X(t).

The backend of the transmitter is identical to that to be used in the circuits of FIG. 1 and FIG. 2. The output of the summer 54 in this case, or the summer 24 of FIGS. 1 and 2, is applied to a bandpass filter 55 having its output applied to a linear RF amplifier 56, the output of which is transmitted via antenna 57. The transmitted signal includes the input signals modulated on subcarriers, the center carrier signal and the two carrier sideband bit sync signals as illustrated in FIG. 5. The carrier and bit sync signals are useful when demodulating the received transmitted signal in order to compensate for selective fading that can occur over a radio path.

In operation, a first pair of signals are quadrature modulated onto a first subcarrier while a second pair of signals are quadrature modulated onto a second subcarrier. The two quadrature modulated subcarriers are then quadrature modulated onto the carrier resulting in the information carrying components signal being spaced from the carrier frequency. A pilot carrier signal and bit sync signals can be inserted between sidebands carrying the twice quadrature modulated information signals. This provides a spectrally efficient signal capable of being successfully transmitted over an unstable channel. Consequently, it can be used in applications, such as land mobile radio where conventional quadrature amplitude modulation cannot be reliably applied.

TABLE 1

```
K0000XMT II.590000BFF80B0020BFF80B0599BFF80B05990020BCE02BCE077F187F    XMT II.1
BC800BCE08B5589BC103BD001BFFFFB60A0BD001BFFC1B60A0BCA00B6880BC8067F0E7F XMT II.2
BCA01B604EB604FB8050B9F50BF880B014BBD001B07CFB604CBD001B00C5B604D7F130F XMT II.3
B204EB104FB604EBF180B004FBCA19B604EBC104BD001BFFC2B6080BCE00BCE1F7F0F1F XMT II.4
BC104BD001BFFC2B6080BFF80B0051BCE00BCE1FBD001B065DB604CBD001B01EE7F101F XMT II.5
B604DBCE00BCE1FBD001B03EBB604CBD001B021BB604DBCE00BCE1FBD001B01357F10BF XMT II.6
B604CBD001B00FDB604DBCE00BCE1FBD001BFF03B604CBD001BFECBB604DBCE007F0C2F XMT II.7
BCE1FBD001BFDEBB604CBD001BFC15B604DBCE00BCE1FBD001BFE12B604CBD0017F0B9F XMT II.8
BF9A3B604DBCE00BCE1FBD001BFF3BB604CBD001BF831B604DBCE00BCE1FBD0017F0B3F XMT II.9
B00C5B604CBD001BF831B604DBCE00BCE1FBD001B01EEB604CBD001BF9A3B604D7F0FBF XMT II10
BCE00BCE1FBD001B021BB604CBD001BFC15B604DBCE00BCE1FBD001B00FDB604C7F0E6F XMT II11
BD001BFECBB604DBCE00BCE1FBD001BFECBB604CBD001B00FDB604DBCE00BCE1F7F07FF XMT II12
BD001BFC15B604CBD001B021BB604DBCE00BCE1FBD001BF9A3B604CBD001B01EE7F104F XMT II13
B604DBCE00BCE1FBD001BF831B604CBD001B00C5B604DBCE00BCE1FBD001BF8317F0EDF XMT II14
B604CBD001BFF3BB604DBCE00BCE1FBD001BF9A3B604CBD001BFE12B604DBCE007F0C9F XMT II15
BCE1FBD001BFC15B604CBD001BFDEBB604DBCE00BCE1FBD001BFECBB604CBD0017F097F XMT II16
BFF03B604DBCE00BCE1FBD001B00FDB604CBD001B0135B604DBCE00BCE1FBD0017F0E7F XMT II17
B021BB604CBD001B03EBB604DBCE00BCE1FBD001B01EEB604CBD001B065DB604D7F114F XMT II18
BCE00BCE1FBD001B00C5B604CBD001B07CFB604DBCE00BCE1FBD001BFF3BB604C7F0C1F XMT II19
BD001B07CFB604DBCE00BCE1FBD001BFE12B604CBD001B065DB604DBCE00BCE1F7F0CCF XMT II20
BD001BFDEBB604CBD001B03EBB604DBCE00BCE1FBD001BFF03B604CBD001B01357F0F3F XMT II21
B604DBCE00BCE1FBD001B0135B604CBD001BFF03B604DBCE00BCE1FBD001B03EB7F0E7F XMT II22
B604CBD001BFDEBB604DBCE00BCE1FBD001B065DB604CBD001BFE12B604DBCE007F0D7F XMT II23
BCE1FBD001B07CFB604CBD001BFF3BB604DBCE00BCE1FBFF80B0036BD100B02007F0DFF XMT II24
BC863BFCA0B059DBCE05BC806BD100B0300BCB1FBFCA0B0601B9E50BF980B01707F0F0F XMT II25
BD100B0320BCB0ABFCA0B064DBD100B032BBCB0ABFCA0B0658BD100B0336BCB0A7F101F XMT II26
BFCA0B0663BD100B0341BCB0ABFCA0B066EBFF80B0184BD10[illegible]320BCB0ABFCA07F0EDF XMT II27
B0621BD100B032BBCB0ABFCA0B062CBD100B0336BCB0ABFC[illegible]637BD100B03417F131F XMT II28
BCB0ABFCA0B0642BCA00BA000BD100B0329BCB09B5D90BFF5ABD100B0334BCB097F0FCF XMT II29
B5D90BFF46BCE15B604CBCA00BA000BD100B033FBCB09B5D90BFF32BD100B034A7F0F8F XMT II30
BCB09B5D90BFF1EBCE15B0017B604DB204EB104FB604EBF180B01B4BCA19B604E7F0F1F XMT II31
BC104BD001BFFC2B6080BCE00BCE1FBC104BD001BFFC2B6080BFF80B01B6BCE007F0DBF XMT II32
BCE1FBCA00BA000BD100B0329BCB09B5D90BFF50BD100B0334BCB09B5D90BFF3C7F0E6F XMT II33
BCE15B604CBCA00BA000BD100B033FBCB09B5D90BFF28BD100B034ABCB09B5D907F0FBF XMT II34
BFF14BCE15B0018B604DBCE00BCE1FBCA00BA000BD100B0329BCB09B5D90BFF467F0E4F XMT II35
BD100B0334BCB09B5D90BFF32BCE15B604CBCA00BA000BD100B033FBCB09B5D907F10EF XMT II36
BFF1EBD100B034ABCB09B5D90BFF0ABCE15B0019B604DBCE00BCE1FBCA00BA0007F0C1F XMT II37
BD100B0329BCB09B5D90BFF3CBD100B0334BCB09B5D90BFF28BCE15B604CBCA007F0E6F XMT II38
BA000BD100B033FBCB09B5C90BFF14BD100B034ABCB09B5C90BFF00BCE15B001A7F105F XMT II39
B604DB203AB6036B2045B6041BCE00BCE1FBCA00BA000BD100B0329BCB09B5D907F147F XMT II40
BFF32BD100B0334BCB09B5D90BFF1EBCE15B604CBCA00BA000BD100B033FBCB097F0EEF XMT II41
B5D90BFF5ABD100B034ABCB09B5D90BFF46BCE15B001BB604DBCE00BCE1FBCA007F0AEF XMT II42
BA000BD100B0329BCB09B5D90BFF28BD100B0334BCB09B5D90BFF14BCE15B604C7F10AF XMT II43
BCA00BA000BD100B033FBCB09B5D90BFF50BD100B034ABCB09B5D90BFF3CBCE157F0DBF XMT II44
B001CB604DBCE00BCE1FBCA00BA000BD100B0329BCB09B5D90BFF1EBD100B03347F10DF XMT II45
BCB09B5D90BFF0ABCE15B604CBCA00BA000BD100B033FBCB09B5D90BFF46BD1007F0D6F XMT II46
B034ABCB09B5D90BFF32BCE15B001DB604DBCE00BCE1FBCA00BA000BD100B03297F0F6F XMT II47
BCB09B5C90BFF14BD100B0334BCB09B5C90BFF00BCE15B604CB2024B6020B202F7F120F XMT II48
B602BBCA00BA000BD100B033FBCB09B5D90BFF3CBD100B034ABCB09B5D90BFF287F0EAF XMT II49
BCE15B001EB604DBCE00BCE1FBCA00BA000BD100B0329BCB09B5D90BFF5ABD1007F0E7F XMT II50
B0334BCB09B5D90BFF46BCE15B604CBCA00BA000BD100B033FBCB09B5D90BFF327F0EDF XMT II51
BD100B034ABCB09B5D90BFF1EBCE15B001FB604DBCE00BCE1FBCA00BA000BD1007F0DCF XMT II52
B0329BCB09B5D90BFF50BD100B0334BCB09B5D90BFF3CBCE15B604CBCA00BA0007F0EFF XMT II53
BD100B033FBCB09B5D90BFF28BD100B034ABCB09B5D90BFF14BCE15B0000B604D7F0FEF XMT II54
BCE00BCE1FBCA00BA000BD100B0329BCB09B5D90BFF46BD100B0334BCB09B5D907F0FBF XMT II55
```

```
BFF32BCE15B604CBCA00BA000BD100B033FBCB09B5D90BFF1EBD100B034ABCB097F0E0F  XMT  I156
B5D90BFF0ABCE15B0001B604DBCE00BCE1FBCA00BA000BD100B0329BCB09B5D907F0F4F  XMT  I157
BFF3CBD100B0334BCB09B5D90BFF28BCE15B604CBCA00BA000BD100B033FBCB097F0E9F  XMT  I158
B5C90BFF14BD100B034ABCB09B5C90BFF00BCE15B0002B604DB203AB6036B20457F137F  XMT  I159
B6041BCE00BCE1FBCA00BA000BD100B0329BCB09B5D90BFF32BD100B0334BCB097F117F  XMT  I160
B5D90BFF1EBCE15B604CBCA00BA000BD100B033FBCB09B5D90BFF5ABD100B034A7F0DBF  XMT  I161
BCB09B5D90BFF46BCE15B0003B604DBCE00BCE1FBCA00BA000BD100B0329BCB097F0EDF  XMT  I162
B5D90BFF28BD100B0334BCB09B5D90BFF14BCE15B604CBCA00BA000BD100B033F7F106F  XMT  I163
BCB09B5D90BFF50BD100B034ABCB09B5D90BFF3CBCE15B0004B604DBCE00BCE1F7F0B8F  XMT  I164
BCA00BA000BD100B0329BCB09B5D90BFF1EBD100B0334BCB09B5D90BFF0ABCE157F0EBF  XMT  I165
B604CBCA00BA000BD100B033FBCB09B5D90BFF46BD100B034ABCB09B5D90BFF327F0F8F  XMT  I166
BCE15B0005B604DBCE00BCE1FBCA00BA000BD100B0329BCB09B5C90BFF14BD1007F10AF  XMT  I167
B0334BCB09B5C90BFF00BCE15B604CB2024B6020B202FB602BBCA00BA000BD1007F151F  XMT  I168
B033FBCB09B5D90BFF3CBD100B034ABCB09B5D90BFF28BCE15B0006B604DBCE007F0D4F  XMT  I169
BCE1FBCA00BA000BD100B0329BCB09B5D90BFF5ABD100B0334BCB09B5D90BFF467F0E1F  XMT  I170
BCE15B604CBCA00BA000BD100B033FBCB09B5D90BFF32BD100B034ABCB09B5D907F100F  XMT  I171
BFF1EBCE15B0007B604DBCE00BCE1FBCA00BA000BD100B0329BCB09B5D90BFF507F0DAF  XMT  I172
BD100B0334BCB09B5D90BFF3CBCE15B604CBCA00BA000BD100B033FBCB09B5D907F0FDF  XMT  I173
BFF28BD100B034ABCB09B5D90BFF14BCE15B0008B604DBCE00BCE1FBCA00BA0007F0DBF  XMT  I174
BD100B0329BCB09B5D90BFF46BD100B0334BCB09B5D90BFF32BCE15B604CBCA007F0F7F  XMT  I175
BA000BD100B033FBCB09B5D90BFF1EBD100B034ABCB09B5D90BFF0ABCE15B00097F0EAF  XMT  I176
B604DBCE00BCE1FBCA00BA000BD100B0329BCB09B5D90BFF3CBD100B0334BCB097F0F3F  XMT  I177
B5D90BFF28BCE15B604CBCA00BA000BD100B033FBCB09B5C90BFF14BD100B034A7F0F9F  XMT  I178
BCB09B5C90BFF00BCE15B000AB604DB203AB6036B2045B6041BCE00BCE1FBCA007F111F  XMT  I179
BA000BD100B0329BCB09B5D90BFF32BD100B0334BCB09B5D90BFF1EBCE15B604C7F0FEF  XMT  I180
BCA00BA000BD100B033FBCB09B5D90BFF5ABD100B034ABCB09B5D90BFF46BCE157F0D6F  XMT  I181
B000BB604DBCE00BCE1FBCA00BA000BD100B0329BCB09B5D90BFF28BD100B03347F11BF  XMT  I182
BCB09B5D90BFF14BCE15B604CBCA00BA000BD100B033FBCB09B5D90BFF50BD1007F0E7F  XMT  I183
B034ABCB09B5D90BFF3CBCE15B000CB604DBCE00BCE1FBCA00BA000BD100B03297F0E7F  XMT  I184
BCB09B5D90BFF1EBD100B0334BCB09B5D90BFF0ABCE15B604CBCA00BA000BD1007F0DCF  XMT  I185
B033FBCB09B5D90BFF46BD100B034ABCB09B5D90BFF32BCE15B000DB604DBCE007F0D7F  XMT  I186
BCE1FBCA00BA000BD100B0329BCB09B5C90BFF14BD100B0334BCB09B5C90BFF007F0FEF  XMT  I187
BCE15B604CB2024B6020B202FB602BBCA00BA000BD100B033FBCB09B5D90BFF3C7F128F  XMT  I188
BD100B034ABCB09B5D90BFF28BCE15B000EB604DBCE00BCE1FBCA00BA000BD1007F0EAF  XMT  I189
B0329BCB09B5D90BFF5ABD100B0334BCB09B5D90BFF46BCE15B604CBCA00BA0007F0EAF  XMT  I190
BD100B033FBCB09B5D90BFF32BD100B034ABCB09B5D90BFF1EBCE15B000FB604D7F0DCF  XMT  I191
BCE00BCE1FBCA00BA000BD100B0329BCB09B5D90BFF50BD100B0334BCB09B5D907F100F  XMT  I192
BFF3CBCE15B604CBCA00BA000BD100B033FBCB09B5D90BFF28BD100B034ABCB097F0DBF  XMT  I193
B5D90BFF14BCE15B0010B604DBCE00BCE1FBCA00BA000BD100B0329BCB09B5D907F100F  XMT  I194
BFF46BD100B0334BCB09B5D90BFF32BCE15B604CBCA00BA000BD100B033FBCB097F0FAF  XMT  I195
B5D90BFF1EBD100B034ABCB09B5D90BFF0ABCE15B0011B604DBCE00BCE1FBCA007F0B8F  XMT  I196
BA000BD100B0329BCB09B5D90BFF3CBD100B0334BCB09B5D90BFF28BCE15B604C7F0F9F  XMT  I197
BCA00BA000BD100B033FBCB09B5C90BFF14BD100B034ABCB09B5C90BFF00BCE157F0F3F  XMT  I198
B0012B604DB203AB6036B2045B6041BCE00BCE1FBCA00BA000BD100B0329BCB097F166F  XMT  I199
B5D90BFF32BD100B0334BCB09B5D90BFF1EBCE15B604CBCA00BA000BD100B033F7F0FAF  XMT  I100
BCB09B5D90BFF5ABD100B034ABCB09B5D90BFF46BCE15B0013B604DBCE00BCE1F7F0B3F  XMT  I101
BCA00BA000BD100B0329BCB09B5D90BFF28BD100B0334BCB09B5D90BFF14BCE157F103F  XMT  I102
B604CBCA00BA000BD100B033FBCB09B5D90BFF50BD100B034ABCB09B5D90BFF3C7F0ECF  XMT  I103
BCE15B0014B604DBCE00BCE1FBCA00BA000BD100B0329BCB09B5D90BFF1EBD1007F0F8F  XMT  I104
B0334BCB09B5D90BFF0ABCE15B604CBCA00BA000BD100B033FBCB09B5D90BFF467F0E1F  XMT  I105
BD100B034ABCB09B5D90BFF32BCE15B0015B604DBCE00BCE1FBCA00BA000BD1007F0FEF  XMT  I106
B0329BCB09B5C90BFF14BD100B0334BCB09B5C90BFF00BCE15B604CB2024B60207F12CF  XMT  I107
B202FB602BBCA00BA000BD100B033FBCB09B5D90BFF3CBD100B034ABCB09B5D907F106F  XMT  I108
BFF28BCE15B0016B604DBCE00BCE1FBFF80B0184BE54CBE64DBE74DBCE26B00007F0B6F  XMT  I109
BFFFEB000BBFFDDB0065BFD64BFF49B003DBFFEBB0005B0000B0001BFFFEB00077F0ACF  XMT  I110
BFFE7BFCC1B001BBFFF9B0002BFFFFB0000B0005BFFEDB0037BFF50BFE77B00787F095F  XMT  I111
BFFD7B000DBFFFDB0000B0003BFFF5B001FBFF93B011BB0014BFFF8B0002B00007F10AF  XMT  I112
B0001BFFFAB0016BFFBEB00E0B0285BFF89B0029BFFF3B0003B0002BFFF3B002E7F0EFF  XMT  I113
BFF7CB0220B01E0BFF7AB002FBFFF3B0002B0002BFFF8B001ABFFB6B01D8B002B7F0D9F  XMT  I114
BFFE4B0009BFFFEB0000BFFFFB0006BFFECB003ABFFC3BFF13B0043BFFE9B00077F07AF  XMT  I115
BFFFFBFFFEB000BBFFDDB0065BFD64BFF49B003DBFFEBB0005B0000B0001BFFFE7F05BF  XMT  I116
B0007BFFE7BFCC1B001BBFFF9B0002BFFFFB0000BFFE5BFFD7BFFCABFFBFBFFB67EFF6F  XMT  I117
BFFB1BFFAEBFFAFBFFB2BFFB9BFFC3BFFCEBFFDCBFFEBBFFFBB000BB001BB00297EFB4F  XMT  I118
B0036B0041B004AB004FB0052B0051B004EB0047B003DB0032B0024B0015B00057F214F  XMT  I119
BFFF5BFFFFB0001BFFFFB0001BFFFFB0001BFFFFB0001BFFFFB0001B0000B00017F0AAF  XMT  I120
BFFFFBFFFFB0001B0001BFFFFBFFFFB0001B0001BFFFFB0000BFFFFB0001B00017F099F  XMT  I121
BFFFFBFFFFB0001B0001BFFFFBFFFFB0001B0000B0001BFFFFB0001BFFFFB00017F099F  XMT  I122
BFFFFB0001BFFFFB0001BFFFFB0000B0000BFFFFB0001BFFFFB0000BFFFFB00017F09BF  XMT  I123
BFFFFB0000BFFFFB0000B0001B0000BFFFFB0000B0001B0000BFFFFB0000B00017F14CF  XMT  I124
B0000B0000B0000BFFFFB0001B0000B0000BFFFFB0001B0000B0000BFFFFB00007F1A5F  XMT  I125
BFFFFB0001B0000B0001BFFFFB0001B0000B0001BFFFFB0001B00007F3A6F            XMT  I126
8       XMT II.5  08-25-87  10:15:36   ASM32020 PC 1.0 86.036            XMT  I127
```

I claim as my invention:

1. A method of transmitting a quadrature amplitude modulated signal comprising the steps of:

quadrature modulating first and second signals onto a first subcarrier, quadrature modulating third and fourth signals onto a second subcarrier,

quadrature modulating said first and second quadrature modulated subcarriers onto a carrier, and

transmitting said quadrature modulated carrier,

2. A method of transmitting a quadrature amplitude modulated signal comprising the steps of;

quadrature modulating first and second signals onto a first subcarrier

quadrature modulating third and fourth signals onto a second subcarrier,

providing a DC component with one of said quadrature modulated subcarriers for producing a pilot carrier,

quadrature modulating said quadrature first and second quadrature modulated subcarriers onto a carrier, and

transmitting said quadrature modulated carrier.

3. A method of transmitting quadrature amplitude modulated signal as defined in claim **1**, comprising the further step of providing a bit sync signal with one of said quadrature modulated subcarriers.

4. A method as defined in claim **3**, in which the signals are digital signals having a predetermined bit rate and the bit sync signal has a frequency that is an integral multiple of said bit rate.

5. A method of transmitting a quadrature amplitude modulated signal, comprising:

reading from memory first and second prototype pulses each including a subcarrier component,

summing said first and second prototype pulses to produce a first quadrature modulated subcarrier,

reading from memory third and fourth prototype pulses each including a subcarrier component,

summing said third and fourth prototype pulses to produce a second quadrature modulated subcarrier,

quadrature modulating a carrier with said first and second quadrature modulated subcarriers, and

transmitting said quadrature modulated carrier.

6. A method of transmitting a quadrature amplitude modulated signal comprising:

reading from memory first and second prototype pulses each including a subcarrier component,

summing said first and second prototype pulses to produce a first quadrature modulated subcarrier,

reading form memory third and fourth prototype pulses each including a subcarrier component,

summing said third and fourth prototype pulses to produce a second quadrature modulated subcarrier,

quadrature modulating a carrier with said first and second quadrature modulated subcarriers,

summing an offset with one of said summed pulses prior to quadrature modulating said carrier, and

transmitting said quadrature modulated carrier,

7. A method of transmitting a quadrature amplitude modulated signals defined in claim **5** including the further step of summing a sync signal with one of said summed pulses prior to quadrature modulating said carrier.

8. An apparatus for transmitting quadrature modulated signals comprising:

means for quadrature modulating first and second signals on a first subcarrier,

means for quadrature modulating third and fourth signals onto a second subcarrier,

means for quadrature modulating said first and second subcarriers onto a carrier, and

means for transmitting said quadrature modulated carrier.

9. An apparatus for transmitting quadrature modulated signals comprising:

means for quadrature modulating first and second signals on a first subcarrier,

means for quadrature modulating third and fourth signals onto a second subcarrier,

means for summing a sync signal with one of said subcarriers,

means for quadrature modulating said first and second subcarriers onto a carrier, and

means for transmitting said quadrature modulated carrier.

10. An apparatus as defined in claim **9**, in which a processor means is used for quadrature modulating said first and second signals and said third and fourth signals.

11. An apparatus as defined in claim **10**, in which said processor means includes a memory means containing a prototype pulse having a subcarrier component, and said first and second subcarriers produced by summing prototype pulses in said microprocessor means.

* * * * *